11-17-00

A / REISSUE

11/16/00 JC860 U.S. PTO

09/714680 JC682 U.S. PTO 11/16/00

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PTO/SB/50 (08-00)
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REISSUE PATENT APPLICATION TRANSMITTAL

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Attorney Docket No.	2802-257-006
First Named Inventor	Bunyan, Michael
Original Patent Number	6,054,198
Original Patent Issue Date (Month/Day/Year)	04/25/2000
Express Mail Label No.	EL635962178US

APPLICATION FOR REISSUE OF: *(Check applicable box)* [X] *Utility Patent* [ ] *Design Patent* [ ] *Plant Patent*

APPLICATION ELEMENTS (37 CFR 1.173)

1. [XX] Fee Transmittal Form *(PTO/ SB/ 56)* *(Submit an original, and a duplicate for fee processing)*
2. [ ] Applicant claims small entity status. See 37 CFR 1.27.
3. [XX] Specification and Claims in double column copy of patent format *(amended, if appropriate)*
4. [XX] Drawing(s) *(proposed amendments, if appropriate)*
5. [XX] Reissue Oath/Declaration (original or copy) *(37 C.F.R. § 1.175) (PTO/SB/51 or 52)*
6. Original U.S. Patent currently assigned?

   [XX] Yes [ ] No

   (If Yes, check applicable box(es))

   [XX] Written Consent of all Assignees *(PTO/SB/53)*

   [ ] 37 C.F.R. § 3.73(b) Statement (PTO/SB/96) [ ] Power of Attorney

ACCOMPANYING APPLICATION PARTS

7. [ ] Statement of status/support for all changes to the claims. See 37 CFR 1.173 (c).
8. [ ] Original U.S. Patent for surrender
   - [ ] Ribboned Original Patent Grant
   - [ ] Statement of Loss (PTO/SB/55)
9. [ ] Foreign Priority Claim *(35 U.S.C. 119)* *(if applicable)*
10. [XX] Information Disclosure Statement (IDS)/PTO-1449 [XX] Copies of IDS Citations
11. [ ] English Translation of Reissue Oath/Declaration *(if applicable)*
12. [XX] Preliminary Amendment
13. [XX] Return Receipt Postcard *(MPEP 503)* *(Should be specifically itemized)*
14. Other: ....
    ....
    ....

15. CORRESPONDENCE ADDRESS

[XX] *Customer Number or Bar Code Label* **23984** PATENT TRADEMARK OFFICE *(Insert Customer No. or Attach bar code label here)* or [ ] *Correspondence address below*

Name	JOHN A. MOLNAR, JR.				
Address	Parker-Hannifin Corporation 6035 Parkland Boulevard				
City	Cleveland	State	Ohio	Zip Code	44124-4141
Country	USA	Telephone	216-896-2212	Fax	216-896-4027

NAME *(Print/Type)*	JOHN A. MOLNAR, JR.	Registration No *(Attorney/Agent)*	36,611
Signature	[signature]	Date	11-16-00

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REISSUE APPLICATION FEE TRANSMITTAL FORM

Docket Number (Optional) 2802-257-006

Claims as Filed - Part 1

Claims in Patent		Number Filed in Reissue Application	(3) Number Extra	Small Entity Rate	Small Entity Fee		Other than a Small Entity Rate	Other than a Small Entity Fee
(A) 19	Total Claims (37 CFR 1.16(j))	(B) 19	**** =	x $_____=		or	x $ 18 =	0
(C) 4	Independent claims (37 CFR 1.16(i))	(D) 4	* 0 =	x $_____=			x $ 80 =	0
			Basic Fee (37 CFR 1.16(h))	$_____				$ 710
			Total Filing Fee	$			OR	$ 710

Claims as Amended - Part 2

	(1) Claims Remaining After Amendment		(2) Highest Number Previously Paid For	(3) Extra Claims Present	Small Entity Rate	Small Entity Fee		Other than a Small Entity Rate	Other than a Small Entity Fee
Total Claims (37 CFR 1.16(j)	*** 19	MINUS	** 20	* = 0	x $_____=			x $ 18 =	0
Independent Claims (37 CFR 1.16(i))	*** 4	MINUS	***** 4	= 0	x $_____=			x $ 80 =	0
				Total Additional Fee		$	OR		$ 0

* If the entry in (D) is less than the entry in (C), Write "0" in column 3.

** If the "Highest Number of Total Claims Previously Paid For" is less than 20, Write "20" in this space.

*** After any cancellation of claims.

**** If "A" is greater than 20, use (B - A); if "A" is 20 or less, use (B - 20).

***** "Highest Number of Independent Claims Previously Paid For" or Number of Independent Claims in Patent (C).

☐ Applicant claims small entity status. See 37 CFR 1.27.

☒ Please charge Deposit Account No. 16-0325 in the amount of 710.00.
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Signature of Applicant, Attorney or Agent of Record

JOHN A. MOLNAR, JR.
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application for Reissue of
U.S. Patent No. 6,054,198

Filed: Herewith

For: Conformal Thermal Interface Material
For Electronic Components

November 16, 2000

Cleveland, Ohio 44124-4141

BOX REISSUE
COMMISSIONER FOR PATENTS
WASHINGTON, DC 20231

PRELIMINARY AMENDMENT IN REISSUE UNDER 37 C.F.R. § 1.173

Please amend the above-identified application for reissue patent as follows:

IN THE CLAIMS

1. (Amended) A method of conductively cooling a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member to define an interface therebetween, said method comprising the steps of:

(a) providing a thermally-conductive material which is form-stable at normal room temperature in a first phase and conformable in a second phase to substantially fill said interface, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and said material consisting essentially of at least one resin or wax component or mixture thereof blended with at least one thermally-conductive filler;

(b) forming said material into a self-supporting and free-standing film layer, said layer consisting essentially of said material and having a thickness of from about 1-10 mils;

(c) applying said layer to one of said heat transfer surfaces;

(d) disposing said heat transfer surfaces in thermal adjacency to define said interface; and

(e) energizing said electronic component effective to heat said layer to a temperature which is above said phase transition temperature.

9. (Amended) A thermally-conductive interface for interposition between a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a

second heat transfer surface of a thermal dissipation member, said interface comprising a self-supporting and free-standing film layer having a thickness of from about 1-10 mils and consisting essentially of a thermally-conductive material which is form-stable at normal room temperature in a first phase and substantially conformable in a second phase to said interface surfaces, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and said material consisting essentially of at least one resin or wax component or mixture thereof blended with at least one thermally-conductive filler.

REMARKS

Reconsideration of the above-identified application for reissue patent is solicited on behalf of the patent owner. An Information Disclosure Statement is filed herewith.

With the present amendment, claims 1-19 are currently pending, with independent claims 1 and 9 having been amended. Particularly, claims 1 and 9 have been amended to expressly recite that the claimed phase-change material (PCM) may be formulated as mixture of at least one resin or wax component. A complete copy of the amended claim program appears in the Appendix annexed hereto.

Considering the support for the amendment to claims 1 and 9, reference may be had to the printed specification of the subject U.S. Patent No. 6,054,198 ("the '198 patent) wherein at col. 8, ll. 16-65 thereof a representative embodiment is disclosed which is based on a mixture of a resin, namely a PSA component, and a wax, namely an α-olefinic thermoplastic component such as Vybar® 260. [*See also* Example, Sample Nos. 3-1, 2, 3, 7, 8, and 10, at col. 10, l. 19, bridging col. 11, l. 38]. Although not termed a "wax" in the specification, α-olefinic thermoplastics such as Vybar® 260 are generally considered to be waxes and are referred to as such in the following issued U.S. Patent Nos. (copies of which are annexed to the Inventors' Declaration filed herewith): 4,217,320 [*See* col. 2, ll. 59-68]; 4,515,740 [*See* col. 7, ll. 58-63]; 5,994,020 [*See* col. 13, ll. 47-63]; and 6,080,800 [*See* col. 7, ll. 29].

To the extent that claims 1 and 9 as amended would be considered to be broader, at least expressly, than the claims as issued, Applicants are mindful of the prohibition against recapturing cancelled subject matter [*See* M.P.E.P. § 1412.02 *and references cited thereat*]. In this regard, it is noted that the corresponding claims 1 and 13 of the application Serial No. 08/801,047 which matured to issue as the '198 patent were amended to recite that the claimed PCM comprises at least one resin or wax component. [*See* Amendment and Response Under 37 C.F.R. § 1.116 dated April 5, 1999, at pages 1-2]. However, and as appears at page 4 of that Response, those amendments, in reciting a "non-metallic, *i.e.*, resin- or waxed-based phase change material," were proffered to distinguish over the metal wafer of the Altoz reference, U.S. Patent No.

4,915,167. Thus, the stated reason for the amendment of claims 1 and 13, now claims 1 and 9, was to exclude metallic formulation rather than to surrender any claim to a non-metallic formulation based on a mixture of resin or waxes

Additionally, in the Examiner's Amendment dated April 22, 1999, claims 1 and 13 further were amended to change "comprising at least one resin or wax component" to "consisting essentially of" language. However, it was made of record at page 3 of that Examiner's Amendment that such language was intended "to preclude the presence of components such as a substrate or reinforcing web." Thus, the purpose of the amendment was to distinguish over prior art which employed such a substrate or reinforcing web rather than to effect a surrender of formulations based on a mixture of resin or waxes. It thereof is submitted that the present amendments to claims 1 and 9 do not effect the recapture of any subject matter which previously had been surrendered by the Applicants.

In view of the foregoing amendments and remarks, the re-issuance of the aforesaid patent respectfully is solicited.

Respectfully submitted,

John A. Molnar, Jr.
Reg. No. 36,611
PARKER-HANNIFIN CORPORATION
6035 Parkland Boulevard
Cleveland, OH 44124-4141
Voice: (216) 896-2212
Fax: (216) 896-4027
E-mail: jmolnar@parker.com

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service on this 16th day of November, 2000, in an envelope as "Express Mail, Post Office to Addressee" Mailing Label Number EL635962178US addressed to: BOX REISSUE, Commissioner for Patents, Washington, D.C. 20231.

John A. Molnar, Jr.

APPENDIX

CLAIMS AS AMENDED

1. (Amended) A method of conductively cooling a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member to define an interface therebetween, said method comprising the steps of:

(a) providing a thermally-conductive material which is form-stable at normal room temperature in a first phase and conformable in a second phase to substantially fill said interface, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and said material consisting essentially of at least one resin or wax component <u>or mixture thereof</u> blended with at least one thermally-conductive filler;

(b) forming said material into a self-supporting and free-standing film layer, said layer consisting essentially of said material and having a thickness of from about 1-10 mils;

(c) applying said layer to one of said heat transfer surfaces;

(d) disposing said heat transfer surfaces in thermal adjacency to define said interface; and

(e) energizing said electronic component effective to heat said layer to a temperature which is above said phase transition temperature.

2. (Pending) The method of claim 1 further comprising an additional step between steps (d) and (e) of applying an external force to at least one of said heat transfers defining said interface.

3. (Pending) The method of claim 1 wherein said thermal dissipation member is a heat sink or a circuit board.

4. (Pending) The method of claim 1 wherein said layer is applied in step (c) to the heat transfer surface of said electronic component.

5. (Pending) The method of claim 1 wherein said self-supporting layer is formed in step (b) by coating a film of said material onto a surface of a release sheet, and wherein said layer is applied in step (c) by adhering said film to one of said heat transfer and removing said release sheet to expose said film.

6. (Pending) The method of claim 1 wherein said material is provided in step (a) as consisting essentially of a blend of:

(i) from about 20 to 80% by weight of a paraffinic wax component having a melting temperature of from about 60-70°C; and

(ii) from about 20 to 80% by weight of one or more thermally-conductive fillers.

7. (Pending) The method of claim 6 wherein said material has a phase transition temperature of from about 60-80°C.

8. (Pending) The method of claim 6 wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

9. (Amended) A thermally-conductive interface for interposition between a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member, said interface comprising a self-supporting and free-standing film layer having a thickness of from about 1-10 mils and consisting essentially of a thermally-conductive material which is form-stable at normal room temperature in a first phase and substantially conformable in a second phase to said interface surfaces, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and said

material consisting essentially of at least one resin or wax component or mixture thereof blended with at least one thermally-conductive filler.

10. (Pending) The interface of claim 9 which is coated as a film onto a surface of a release sheet.

11. (Pending) The interface of claim 9 wherein said material consisting essentially of a blend of:

(a) from about 20 to 80% by weight of a paraffinic wax component having a melting temperature of from about 60-70°C; and

(b) from about 20 to 80% by weight of one or more thermally-conductive fillers.

12. (Pending) The interface of claim 11 wherein said material has a phase transition temperature of from about 60-80°C.

13. (Pending) The interface of claim 11 wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

14. (Pending) A method of conductively cooling a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member to define an interface therebetween, said method comprising the steps of:

(a) providing a thermally-conductive material which is form-stable at normal room temperature in a first phase and conformable in a second phase to substantially fill said interface, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component and comprising a blend of:

(i) from about 25 to 50% by weight of an acrylic pressure sensitive adhesive component having a melting temperature of from about 90-100°C;

(ii) from about 50 to 75% by weight of an α-olefinic, thermoplastic component having a melting temperature of from about 50-60°C; and

(iii) from about 20 to 80% by weight of one or more thermally-conductive fillers;

(b) forming said material into a self-supporting layer;

(c) applying said layer to one of said heat transfer surfaces;

(d) disposing said heat transfer surfaces in thermal adjacency to define said interface; and

(e) energizing said electronic component effective to heat said layer to a temperature which is above said phase transition temperature.

15. (Pending) The method of claim 14 wherein said material has a phase transition temperature of from about 70-80°C.

16. (Pending) The method of claim 14 wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

17. (Pending) A thermally-conductive interface for interposition between a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member, said interface comprising a self-supporting layer of a thermally-conductive material which is form-stable at normal room temperature in a first phase and substantially conformable in a second phase to said interface surfaces, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and comprising a blend of:

(a) from about 25 to 50% by weight of an acrylic pressure sensitive adhesive component having a melting temperature of from about 90-100°C;

(b) from about 50 to 75% by weight of an α-olefinic, thermoplastic component having a melting temperature of from about 50-60°C; and

(c) from about 20 to 80% by weight of one or more thermally-conductive fillers.

18. (Pending) The interface of claim 17 wherein said material has a phase transition temperature of from about 70-80°C.

19. (Pending) The interface of claim 17 wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

09714580.111500

CONFORMAL THERMAL INTERFACE MATERIAL FOR ELECTRONIC COMPONENTS

This application claims the benefit of U.S. Provisional Application No.: 60/016,488 filing date Apr. 29, 1996.

BACKGROUND OF THE INVENTION

The present invention relates broadly to a heat transfer material which is interposable between the thermal interfaces of a heat-generating, electronic component and a thermal dissipation member, such as a heat sink or circuit board, for the conductive cooling of the electronic component. More particularly, the invention relates to a self-supporting, form-stable film which melts or softens at a temperature or range within the operating temperature range of the electronic component to better conform to the thermal interfaces for improved heat transfer from the electronic component to the thermal dissipation member.

Circuit designs for modern electronic devices such as televisions, radios, computers, medical instruments, business machines, communications equipment, and the like have become increasingly complex. For example, integrated circuits have been manufactured for these and other devices which contain the equivalent of hundreds of thousands of transistors. Although the complexity of the designs has increased, the size of the devices has continued to shrink with improvements in the ability to manufacture smaller electronic components and to pack more of these components in an ever smaller area.

As electronic components have become smaller and more densely packed on integrated boards and chips, designers and manufacturers now are faced with the challenge of how to dissipate the heat which is ohmicly or otherwise generated by these components. Indeed, it is well known that many electronic components, and especially semiconductor components such as transistors and microprocessors, are more prone to failure or malfunction at high temperatures. Thus, the ability to dissipate heat often is a limiting factor on the performance of the component.

Electronic components within integrated circuit traditionally have been cooled via forced or convective circulation of air within the housing of the device. In this regard, cooling fins have been provided as an integral part of the component package or as separately attached thereto for increasing the surface area of the package exposed to convectively-developed air currents. Electric fans additionally have been employed to increase the volume of air which is circulated within the housing. For high power circuits and the smaller but more densely packed circuits typical of current electronic designs, however, simple air circulation often has been found to be insufficient to adequately cool the circuit components.

Heat dissipation beyond that which is attainable by simple air circulation may be effected by the direct mounting of the electronic component to a thermal dissipation member such as a "cold plate" or other heat sink. The heat sink may be a dedicated, thermally-conductive metal plate, or simply the chassis of the device. However, and as is described in U.S. Pat. No. 4,869,954, the faying thermal interface surfaces of the component and heat sink typically are irregular, either on a gross or a microscopic scale. When the interfaces surfaces are mated, pockets or void spaces are developed therebetween in which air may become entrapped. These pockets reduce the overall surface area contact within the interface which, in turn, reduces the efficiency of the heat transfer therethough. Moreover, as it is well known that air is a relatively poor thermal conductor, the presence of air pockets within the interface reduces the rate of thermal transfer through the interface.

To improve the efficiency of the heat transfer through the interface, a layer of a thermally-conductive material typically is interposed between the heat sink and electronic component to fill in any surface irregularities and eliminate air pockets. Initially employed for this purpose were materials such as silicone grease or wax filled with a thermally-conductive filler such as aluminum oxide. Such materials usually are semi-liquid or sold at normal room temperature, but may liquefy or soften at elevated temperatures to flow and better conform to the irregularities of the interface surfaces.

For example, U.S. Pat. No. 4,299,715 discloses a wax-like, heat-conducting material which is combined with another heat-conducting material, such as a beryllium, zinc, or aluminum oxide powder, to form a mixture for completing a thermally-conductive path from a heated element to a heat sink. A preferred wax-like material is a mixture of ordinary petroleum jelly and a natural or synthetic wax, such as beeswax, palm wax, or mineral wax, which mixture melts or becomes plastic at a temperature above normal room temperature. The material can be excoriated or ablated by marking or rubbing, and adheres to the surface on which it was rubbed. In this regard, the material may be shaped into a rod, bar, or other extensible form which may be carried in a pencil-like dispenser for application.

U.S. Pat. No. 4,466,483 discloses a thermally-conductive, electrically-insulating gasket. The gasket includes a web or tape which is formed of a material which can be impregnated or loaded with an electrically-insulating, heat conducting material. The tape or web functions as a vehicle for holding the meltable material and heat conducting ingredient, if any, in a gasket-like form. For example, a central layer of a solid plastic material may be provided, both sides of which are coated with a meltable mixture of wax, zinc oxide, and a fire retardant.

U.S. Pat. No. 4,473,113 discloses a thermally-conductive, electrically-insulating sheet for application to the surface of an electronic apparatus. The sheet is provided as having a coating on each side thereof a material which changes state from a solid to a liquid within the operating temperature range of the electronic apparatus. The material may be formulated as a meltable mixture of wax and zinc oxide.

U.S. Pat. No. 4,764,845 discloses a thermally-cooled electronic assembly which includes a housing containing electronic components. A heat sink material fills the housing in direct contact with the electronic components for conducting heat therefrom. The heat sink material comprises a paste-like mixture of particulate microcrystalline material such as diamond, boron nitride, or sapphire, and a filler material such as a fluorocarbon or paraffin.

The greases and waxes of the aforementioned types heretofore known in the art, however, generally are not self-supporting or otherwise form stable at room temperature and are considered to be messy to apply to the interface surface of the heat sink or electronic component. To provide these materials in the form of a film which often is preferred for ease of handling, a substrate, web, or other carrier must be provided which introduces another interface layer in or between which additional air pockets may be formed. Moreover, use of such materials typically involves hand application or lay-up by the electronics assembler which increases manufacturing costs.

Alternatively, another approach is to substitute a cured, sheet-like material for the silicone grease or wax material. Such materials may be compounded as containing one or more thermally-conductive particulate fillers dispersed within a polymeric binder, and may be provided in the form of cured sheets, tapes, pads, or films. Typical binder materials include silicones, urethanes, thermoplastic rubbers, and other elastomers, with typical fillers including aluminum oxide, magnesium oxide, zinc oxide, boron nitride, and aluminum nitride.

Exemplary of the aforesaid interface materials is an alumina or boron nitride-filled silicone or urethane elastomer which is marketed under the name CHO-THERM® by the Chomerics Division of Parker-Hannifin Corp., Woburn, Mass. Additionally, U.S. Pat. No. 4,869,954 discloses a cured, form-stable, sheet-like, thermally-conductive material for transferring thermal energy. The material is formed of a urethane binder, a curing agent, and one or more thermally conductive fillers. The fillers may include aluminum oxide, aluminum nitride, boron nitride, magnesium oxide, or zinc oxide.

U.S. Pat. No. 4,782,893 discloses a thermally-conductive, electrically-insulative pad for placement between an electronic component and its support frame. The pad is formed of a high dielectric strength material in which is dispersed diamond powder. In this regard, the diamond powder and a liquid phase of the high dielectric strength material may be mixed and then formed into a film and cured. After the film is formed, a thin layer thereof is removed by chemical etching or the like to expose the tips of the diamond particles. A thin boundary layer of copper or other metal then is bonded to the top and bottom surfaces of the film such that the exposed diamond tips extend into the surfaces to provide pure diamond heat transfer paths across the film. The pad may be joined to the electronic component and the frame with solder or an adhesive.

U.S. Pat. No. 4,965,699 discloses a printed circuit device which includes a memory chip mounted on a printed circuit card. The card is separated from an associated cold plate by a layer of a silicone elastomer which is applied to the surface of the cold plate.

U.S. Pat. No. 4,974,119 discloses a heat sink assembly which includes an electronic component supported on a printed circuit board in a spaced-apart relationship from a heat dispersive member. A thermally-conductive, elastomeric layer is interposed between the board and the electronic component. The elastomeric member may be formed of silicone and preferably includes a filler such as aluminum oxide or boron nitride.

U.S. Pat. No. 4,979,074 discloses a printed circuit board device which includes a circuit board which is separated from a thermally-conductive plate by a pre-molded sheet of silicone rubber. The sheet may be loaded with a filler such as alumina or boron nitride.

U.S. Pat. No. 5,137,959 discloses a thermally-conductive, electrically insulating interface material comprising a thermoplastic or cross linked elastomer filled with hexagonal boron nitride or alumina. The material may be formed as a mixture of the elastomer and filler, which mixture then may be cast or molded into a sheet or other form.

U.S. Pat. No. 5,194,480 discloses another thermally-conductive, electricallyinsulating filled elastomer. A preferred filler is hexagonal boron nitride. The filled elastomer may be formed into blocks, sheets, or films using conventional methods.

U.S. Pat. Nos. 5,213,868 and 5,298,791 disclose a thermally-conductive interface material formed of a polymeric binder and one or more thermally-conductive fillers. The fillers may be particulate solids, such as aluminum oxide,.aluminum nitride, boron nitride, magnesium oxide, or zinc oxide. The material may be formed by casting or molding, and preferably is provided as a laminated acrylic pressure sensitive adhesive (PSA) tape. At least one surface of the tape is provided as having channels or through-holes formed therein for the removal of air from between that surface and the surface of a substrate such as a heat sink or an electronic component.

U.S. Pat. No. 5,321,582 discloses an electronic component heat sink assembly which includes a thermally-conductive laminate formed of polyamide which underlies a layer of a boron nitride-filled silicone. The laminate is interposed between the electronic component and the housing of the assembly.

Sheet-like materials of the above-described types have garnered general acceptance for use as interface materials in conductively-cooled electronic component assemblies. For some applications, however, heavy fastening elements such as springs, clamps, and the like are required to apply enough force to conform these materials to the interface surfaces to attain enough surface for efficient thermal transfer. Indeed, for certain applications, materials such as greases and waxes which liquefy, melt, or soften at elevated temperature sometimes are preferred as better conforming to the interface surfaces. It therefore will be appreciated that further improvements in these types of interface materials and methods of applying the same would be well-received by the electronics industry. Especially desired would be a thermal interface material which is self-supporting and form-stable at room temperature, but which is softenable or meltable at temperatures within the operating temperature range of the electronic component to better conform to the interface surfaces.

BROAD STATEMENT OF THE INVENTION

The present invention is directed to a heat transfer material which is interposable between the thermal interfaces of a heat-generating, electronic component and a thermal dissipation member. The material is of the type which melts or softens at a temperature or range within the operating temperature range of the electronic component to better conform to the thermal interfaces for improved heat transfer from the electronic component to the thermal dissipation member. Unlike the greases or waxes of such type heretofore known in the art, however, the interface material of the present invention is form-stable and self-supporting at room temperature. Accordingly, the material may be formed into a film or tape which may be applied using automated equipment to, for example, the interface surface of a thermal dissipation member such as a heat sink. In being self-supporting, no web or substrate need be provided which would introduce another layer into the interface between which additional air pockets could be formed.

It therefore is a feature of the present invention to provide for the conductive cooling a heat-generating electronic component. The component has an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of an associated thermal dissipation member to define an interface therebetween. A thermally-conductive material is provided which is form-stable at normal room temperature in a first phase and conformable in a second phase to substantially fill the interface. The material, which has a transition temperature from the first phase to the

second phase within the operating temperature range of the electronic component, is formed into a self-supporting layer. The layer is applied to one of the heat transfer surfaces, which surfaces then are disposed in thermal adjacency to define the interface. The energization of the electronic component is effective to heat the layer to a temperature which is above the phase transition temperature.

It is a further feature of the invention to provide a thermally-conductive interface for conductively cooling a heat-generating electronic component having an associated thermal dissipation member such as a heat sink. The interface is formed as a self-supporting mono-layer of a thermally-conductive material which is form-stable at normal room temperature in a first phase and substantially conformable in a second phase to the interface surfaces of the electronic component and thermal dissipation member. The material has a transition temperature from the first phase to the second phase which is within the operating temperature range of the electronic component.

Advantages of the present invention include a thermal interface material which melts or softens to better conform to the interfaces surfaces, but which is self-supporting and form-stable at room temperature for ease of handling and application. Further advantages include an interface material which may be formed into a film or tape without a web or other supporting substrate, and which may be applied using automated methods to, for example, the interface surface of a thermal dissipation member. Such member then may be shipped to a manufacturer for direct installation into a circuit board to thereby obviate the need for hand lay-up of the interface material. Still further advantages include a thermal interface formulation which may be tailored to provide controlled thermal and viscometric properties. These and other advantages will be readily apparent to those skilled in the art based upon the disclosure contained herein.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings wherein:

FIG. **1** is a fragmentary, cross-sectional view of an electrical assembly wherein a heatgenerating electronic component thereof is conductively cooled in accordance with the present invention via the provision of an interlayer of a thermally-conductive material within the thermal interace between the heat transfer surfaces of the component and an associated thermal dissipation member;

FIG. **2** is a view of a portion of the thermal interface of FIG. **1** which is enlarged to detail the morphology thereof,

FIG. **3** is a cross-sectional end view which shows the thermally-conductive material of FIG. **1** as coated as a film layer onto a surface of a release sheet, which sheet is rolled to facilitate the dispensing of the film; and

FIG. **4** is a view of a portion of the film and release sheet roll of FIG. **3** which is enlarged to detail the structure thereof

The drawings will be described further in connection with the following Detailed Description of the Invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings wherein corresponding reference characters indicate corresponding elements throughout the figures, shown generally at **10** in FIG. **1** is an electrical assembly which includes a heat-generating digital or analog electronic component, **12**, supported on an associated printed circuit board (PCB) or other substrate, **14**. Electrical component **12** may be an integrated microchip, microprocessor, transistor, or other semiconductor, or an ohmic or other heat-generating subassembly such as a diode, relay, resistor, transformer, amplifier, diac, or capacitor. Typically, component **12** will have an operating temperature range of from about 60–80° C. For the electrical connection of component **12** to board **14**, a pair of leads or pins, **16***a* and **16***b*, are provided as extending from either end of component **12** into a soldered or other connection with board **14**. Leads **16** additionally may support component **12** above board **14** to define a gap, represented at **17**, of about 3 mils (75 microns) therebetween. Alternatively, component **12** may be received directly on board **14**.

As supported on board 14, electronic component **12** presents a first heat transfer surface, **18**, which is disposable in a thermal, spaced-apart adjacency with a corresponding second heat transfer surface, **22**, of an associated thermal dissipation member, **20**. Dissipation member **20** is constructed of a metal material or the like having a heat capacity relative to that of component **12** to be effective is dissipating thermal energy conducted or otherwise transferred therefrom. For purposes of the present illustration, thermal dissipation member **20** is shown as a heat sink having a generally planar base portion, **24**, from which extends a plurality of cooling fins, one of which is referenced at **26**. With assembly **10** configured as shown, fins **26** assist in the convective cooling of component **12**, but alternatively may be received within an associated cold plate or the like, not shown, for further conductive dissipation of the thermal energy transferred from component **12**.

The disposition of first heat transfer surface **18** of electronic component **12** in thermal adjacency with second heat transfer surface **22** of dissipation member **20** defines a thermal interface, represented at **28**, therebetween. A thermally-conductive interlayer, **30**, is interposed within interface **28** between heat transfer surfaces **18** and **22** for providing a conductive path therethrough for the transfer of thermal energy from component **12** to dissipation member **20**. Such path may be employed without or in conjunction with convective air circulation for effecting the cooling of component **12** and ensuring that the operating temperature thereof is maintained below specified limits.

Although thermal dissipation member **20** is shown to be a separate heat sink member, board **14** itself may be used for such purpose by alternatively interposing interlayer **30** between surface **32** thereof and corresponding surface **34** of electronic component **12**. In either arrangement, a clip, spring, or clamp or the like (not shown) additionally may be provided for applying an external force, represented at **32**, of from about 1–2 lbs, for improving the interface area contact between interlayer **30** and surfaces **18** and **22** or **32** and **34**.

In accordance with the precepts of the present invention, interlayer **30** is formed of a self-supporting film, sheet, or other layer of a thermally-conductive material. By "self-supporting," it is meant that interlayer **30** is free-standing without the support of a web or substrate which would introduce another layer into the thermal interface between air pockets could be formed. Typically, the film or sheet of interlayer **30** will have a thickness of from about 1–10 mils (25–250 microns) depending upon the particular geometry of assembly **10**.

The thermally-conductive material forming interlayer **30** is formulated to be form-stable at normal room temperature, i.e., about 25° C., in a first phase, which is solid, semi-solid,

glassy, or crystalline, but to be substantially conformable in a second phase, which is a liquid, semi-liquid, or otherwise viscous melt, to interface surfaces **18** and **22** of, respectively, electronic component **12** and thermal dissipation member **20**. The transition temperature of the material, which may be its melting or glass transition temperature, is preferably from about 60 or 70° C. to about 80° C., and is tailored to fall within the operating temperature of electronic component **12**.

Further in this regard, reference may be had to FIG. **2** wherein an enlarged view of a portion of interface **28** is illustrated to detail the internal morphology thereof during the energization of electronic component **12** effective to heat interlayer **30** to a temperature which is above its phase transition temperature. Interlayer **30** accordingly is shown to have been melted or otherwise softened from a form-stable solid or semi-solid phase into a flowable or otherwise conformable liquid or semi-liquid viscous phase which may exhibit relative intermolecular chain movement. Such viscous phase provides increased surface area contact with interface surfaces **18** and **22**, and substantially completely fills interface **28** via the exclusion of air pockets or other voids therefrom to thereby improve both the efficiency and the rate of heat transfer through interface. Moreover, as depending on, for example, the melt flow index or viscosity of interlayer **30** and the magnitude of any applied external pressure **36** (FIG. **1**), the interface gap between surfaces **18** and **22** may be narrowed to further improve the efficiency of the thermal transfer therebetween. Any latent heat associated with the phase change of the material forming interlayer **30** additionally contributes to the cooling of component **12**.

Unlike the greases or waxes of such type heretofore known in the art, however, interlayer of the present invention advantageously is form-stable and self-supporting at room temperature. Accordingly, and as is shown generally at **40** in FIG. **3**, interlayer **30** advantageously may be provided in a rolled, tape form to facilitate its application to the substrate by an automated process. As may be better appreciated with additional reference to FIG. **4** wherein a portion, **42**, of tape **40** is shown in enhanced detail, tape **40** may be formed by applying a film of interlayer **30** to a length of face stock, liner, or other release sheet, **44**. Interlayer **30** may be applied to a surface, **46**, of release sheet **44** in a conventional manner, for example, by a direct process such as spraying, knife coating, roller coating, casting, drum coating, dipping, or like, or an indirect transfer process utilizing a silicon release sheet. A solvent, diluent, or other vehicle may be provided to lower the viscosity of the material forming interlayer **30**. After the material has been applied, the release sheet may be dried to flash the solvent and leave an adherent, tack-free film, coating, or other residue of the material thereon.

As is common in the adhesive art, release sheet **44** may be provided as a strip of a waxed, siliconized, or other coated paper or plastic sheet or the like having a relatively low surface energy so as to be removable without appreciable lifting of interlayer **30** from the substrate to which it is ultimately applied. Representative release sheets include face stocks or other films of plasticized polyvinyl chloride, polyesters, cellulosics, metal foils, composites, and the like.

In the preferred embodiment illustrated, tape **40** may be sectioned to length, and the exposed surface, **48**, of interlayer **30** may be applied to interface surface **22** of dissipation member **20** (FIG. **1**) prior to its installation in assembly **10**. In this regard, interlayer exposed surface **48** may be provided as coated with a thin film of a pressure sensitive adhesive or the like for adhering interlayer **30** to dissipation member **20**. Alternatively, interface surface **22** of dissipation member **20** may be heated to melt a boundary layer of interlayer surface **48** for its attachment via a "hot-melt" mechanism.

With tape **40** so applied and with release sheet **44** protecting the unexposed surface, **50**, of interlayer **30**, dissipation member **20** (FIG. **1**) may be packaged and shipped as an integrated unit to an electronics manufacturer, assembler, or other user. The user then simply may remove release sheet **44** to expose surface **50** of interlayer **30**, position surface **50** on heat transfer surface **18** of electronic component **12**, and lastly apply a clip or other another means of external pressure to dispose interlayer surface **50** in an abutting, heat transfer contact or other thermal adjacency with electronic component surface **18**.

In one preferred embodiment, interlayer **30** is formulated as a form-stable blend of: (a) from about 25 to 50% by weight of a pressure sensitive adhesive (PSA) component having a melting temperature of from about 90–100° C.; (b) from about 50 to 75% by weight of an α-olefinic, thermoplastic component having a melting temperature of from about 50–60° C.; and (c) from about 20 to 80% by weight of one or more thermally-conductive fillers. "Melting temperature" is used herein in its broadest sense to include a temperature or temperature range evidencing a transition from a form-stable solid, semi-solid, crystalline, or glassy phase to a flowable liquid, semi-liquid, or otherwise viscous phase or melt which may be characterized as exhibiting intermolecular chain rotation.

The PSA component generally may be of an acrylic-based, hot-melt variety such as a homopolymer, copolymer, terpolymer, interpenetrating network, or blend of an acrylic or (meth)acrylic acid, an acrylate such as butyl acrylate, and/or an amide such as acrylamide. The term "PSA" is used herein in its conventional sense to mean that the component is formulated has having a glass transition temperature, surface energy, and other properties such that it exhibits some degree of tack at normal room temperature. Acrylic hot-melt PSAs of such type are marketed commercially by Heartland Adhesives, Germantown, Wis., under the trade designations "H600" and "H251."

The α-olefinic thermoplastic component preferably is a polyolefin which may be characterized as a "low melt" composition. A representative material of the preferred type is an amorphous polymer of a C_{10} or higher alkene which is marketed commercially by Petrolite Corporation, Tulsa, Okla., under the trade designation "Vybar® 260." Such material may be further characterized as is set forth in Table 1.

TABLE 1

Physical Properties of Representative Olefinic Polymer Component (Vybar ® 260)

Molecular Weight	2600 g/mol
Melting Point (ASTM D 36)	130° F. (54° C.)
Viscosity (ASTM D 3236) @ 210° F. (99° C.)	357.5 cP
Penetration (ASTM D 1321) @ 77° F. (25° C.)	12 mm
Density (ASTM D 1168)	
@ 75° F. (24° C.)	0.90 g/cm³
@ 200° F. (93° C.)	0.79 g/cm³
Iodine Number (ASTM D 1959)	15

By varying the ratio within the specified limits of the PSA to the thermoplastic component, the thermal and viscometric

properties of the interlayer formulation may be tailored to provide controlled thermal and viscometric properties. In particular, the phase transition temperature and melt flow index or viscosity of the formulation may be selected for optimum thermal performance with respect to such variables as the operating temperature of the heat generating electronic component, the magnitude of any applied external pressure, and the configuration of the interface.

In an alternative embodiment, a paraffinic wax or other natural or synthetic ester of a long-chain (C_{16} or greater) carboxylic acid and alcohol having a melting temperature of from about 60–70° C. may be substituted for the thermoplastic and PSA components to comprise about 20–80% by weight of the formulation. A preferred wax is marketed commercially by Bareco Products of Rock Hill, S.C. under the trade designation "Ultraflex® Amber," and is compounded as a blend of clay-treated microcrystalline and amorphous constituents. Such wax is additionally characterized in Table 2 which follows.

TABLE 2

Physical Properties of Representative Paraffinic Wax Component (Ultraflex ® Amber)

Melting Point (ASTM D 127)	156° F. (69° C.)
Viscosity (ASTM D 3236) @ 210° F. (99° C.)	13 cP
Penetration (ASTM D 1321)	
@ 77° F. (25° C.)	29 mm
@ 110° F. (43° C.)	190 mm
Density (ASTM D 1168)	
@ 77° F. (25° C.)	0.92 g/cm^3
@ 210° F. (99° C.)	0.79 g/cm^3

In either of the described embodiments, the resin or wax components form a binder into which the thermally-conductive filler is dispersed. The filler is included within the binder in a proportion sufficient to provide the thermal conductivity desired for the intended application. The size and shape of the filler is not critical for the purposes of the present invention. In this regard, the filler may be of any general shape including spherical, flake, platelet, irregular, or fibrous, such as chopped or milled fibers, but preferably will be a powder or other particulate to assure uniform dispersal and homogeneous mechanical and thermal properties. The particle size or distribution of the filler typically will range from between about 0.25–250 microns (0.01–10 mils), but may further vary depending upon the thickness of interface **28** and/or interlayer **30**.

It additionally is preferred that the filler is selected as being electrically-nonconductive such that interlayer **30** may provide an electrically-insulating but thermally-conductive barrier between electronic component **12** and thermal dissipation member **20**. Suitable thermally-conductive, electrically insulating fillers include boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof Such fillers characteristically exhibit a thermal conductivity of about 25–50 W/m-°K.

Additional fillers and additives may be included in interlayer **30** to the extent that the thermal conductivity and other physical properties thereof are not overly compromised. As aforementioned, a solvent or other diluent may be employed during compounding to lower the viscosity of the material for improved mixing and delivery. Conventional wetting opacifying, or anti-foaming agents, pigments, flame retardants, and antioxidants also may be added to the formulation depending upon the requirements of the particular application envisioned. The formulation may be compounded in a conventional mixing apparatus.

Although not required, a carrier or reinforcement member (not shown) optionally may be incorporated within interlayer **30** as a separate internal layer. Conventionally, such member may be provided as a film formed of a thermoplastic material such as a polyimide, or as a layer of a woven fiberglass fabric or an expanded aluminum mesh. The reinforcement further supports the interlayer to facilitate its handling at higher ambient temperatures and its die cutting into a variety of geometries.

The Example to follow, wherein all percentages and proportions are by weight unless otherwise expressly indicated, is illustrative of the practicing of the invention herein involved, but should not be construed in any limiting sense.

EXAMPLE

Master batches representative of the interlayer formulations of the present invention were compounded for characterization according to the following schedule:

TABLE 3

Representative Interlayer Formulations

Sample No.	Vybar ® 260[1] (wt. %)	H600[2] (wt. %)	Ultraflex ® Amber[3] (wt. %)	Filler (wt. %) BN[4]	ZnO_2[5]	Al[6]
3-1	45	22				33
3-2	47	17				36
3-3	47	17		6		30
3-6			40			60
3-7	40	19			41	
3-8	50	25		25		
3-10	34	16			50	
5-1			67	33		

[1]α-olefinic thermoplastic, Petrolite Corp., Tulsa, OK
[2]acrylic PSA, Heartland Adhesives, Germantown, WI
[3]paraffinic wax, Bareco Products Corp. Rock Hill, SC
[4]Boron nitride, HCP particle grade, Advanced Ceramics, Cleveland, OH
[5]Zinc oxide, Midwest Zinc, Chicago, IL; Wittaker, Clark & Daniels, Inc., S. Plainfield, NJ
[6]Alumina, R1298, Alcan Aluminum, Union, NJ

The Samples were thinned to about 30–70% total solids with toluene or xylene, cast, and then dried to a film thickness of from about 2.5 to 6 mils. When heated to a temperature of between about 55–65° C., the Samples were observed to exhibit a conformable grease or paste-like consistency. The following thermal properties were measured and compared with conventional silicone grease (Dow 340, Dow Corning, Midland, Mich.) and metal foil-supported wax (Crayotherm™, Crayotherm Corp., Anaheim, Calif.) formulations:

TABLE 4

Thermal Properties of Representative and Comparative Interlayer Formulations

Sample No.	Formulation	Filler (wt. %)	Thickness (mils)	Thermal Impedance[5] (° C.-in/w)	Thermal Conductivity[5] (w/m-° K.)
3-1	blend	62% Al	6	0.14	1.7
3-2	blend	62% Al	4	0 12	1.3
3-3	blend	62% Al/BN	4	0.09	1.7

TABLE 4-continued

Thermal Properties of Representative and Comparative Interlayer Formulations					
Sample No.	Formulation	Filler (wt. %)	Thickness (mils)	Thermal Impedance[5] (° C.-in/w)	Thermal Conductivity[5] (w/m-° K.)
3-6	wax[2]	60% Al	2 5	0.04	2.3
5-1	wax	50% BN	4	0.10	1.5
3-7	blend	62% ZnO_2	4	0.14	1.1
3-8	blend	30% BN	2 5	0.07	1.5
3-10	blend	70% ZnO_2	3	0.12	0.95
Crayotherm	wax/foil[3]	ZnO_2	2.5	0.11	0.93
3-2	blend	62% Al	5	0.26	0.74
3-6	wax	60% Al	5	0.30	0.65
5-1	wax	50% BN	5	0.12	1.64
Dow 340	grease[4]	ZnO_2	5 (true [6])	0.36	0.54

[1]blend of Vybar ® and H600
[2]Ultraflex ® Amber
[3]metal foil-supported wax
[4]silicone grease
[5]measured using from about 10–300 psi applied external pressure
[6] spacers used to control thickness

The foregoing results confirm that the interlayer formulations of the present invention retain the preferred conformal and thermal properties of the greases and waxes heretofore known in the art. However, such formulations additionally are form-stable and self-supporting at room temperature, thus affording easier handling and application and obviating the necessity for a supporting substrate, web, or other carrier.

As it is anticipated that certain changes may be made in the present invention without departing from the precepts herein involved, it is intended that all matter contained in the foregoing description shall be interpreted as illustrative and not in a limiting sense. All references cited herein are expressly incorporated by reference.

What is claimed:

1. A method of conductively cooling a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member to define an interface therebetween, said method comprising the steps of:

(a) providing a thermally-conductive material which is form-stable at normal room temperature in a first phase and conformable in a second phase to substantially fill said interface, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and said material consisting essentially of at least one resin or wax component blended with at least one thermally-conductive filler;

(b) forming said material into a self-supporting and free-standing film layer, said layer consisting essentially of said material and having a thickness of from about 1–10 mils;

(c) applying said layer to one of said heat transfer surfaces;

(d) disposing said heat transfer surfaces in thermal adjacency to define said interface; and

(e) energizing said electronic component effective to heat said layer to a temperature which is above said phase transition temperature.

2. The method of claim 1 further comprising an additional step between steps (d) and (e) of applying an external force to at least one of said heat transfers defining said interface.

3. The method of claim 1 wherein said thermal dissipation member is a heat sink or a circuit board.

4. The method of claim 1 wherein said layer is applied in step (c) to the heat transfer surface of said electronic component.

5. The method of claim 1 wherein said self-supporting layer is formed in step (b) by coating a film of said material onto a surface of a release sheet, and wherein said layer is applied in step (c) by adhering said film to one of said heat transfer and removing said release sheet to expose said film.

6. The method of claim 1 wherein said material is provided in step (a) as consisting essentially of a blend of:

(i) from about 20 to 80% by weight of a paraffinic wax component having a melting temperature of from about 60–70° C.; and

(ii) from about 20 to 80% by weight of one or more thermally-conductive fillers.

7. The method of claim 6 wherein said material has a phase transition temperature of from about 60–80° C.

8. The method of claim 6 wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

9. A thermally-conductive interface for interposition between a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member, said interface comprising a self-supporting and free-standing film layer having a thickness of from about 1–10 mils and consisting essentially of a thermally-conductive material which is form-stable at normal room temperature in a first phase and substantially conformable in a second phase to said interface surfaces, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and said material consisting essentially of at least one resin or wax component blended with at least one thermally-conductive filler.

10. The interface of claim 9 which is coated as a film onto a surface of a release sheet.

11. The interface of claim 9 wherein said material consisting essentially of a blend of:

(a) from about 20 to 80% by weight of a paraffinic wax component having a melting temperature of from about 60–70° C.; and

(b) from about 20 to 80% by weight of one or more thermally-conductive fillers.

12. The interface of claim 11 wherein said material has a phase transition temperature of from about 60–80° C.

13. The interface of claim 11 wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

14. A method of conductively cooling a heat-generating electronic component having an operating temperature

range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member to define an interface therebetween, said method comprising the steps of:

(a) providing a thermally-conductive material which is form-stable at normal room temperature in a first phase and conformable in a second phase to substantially fill said interface, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component and comprising a blend of:
   (i) from about 25 to 50% by weight of an acrylic pressure sensitive adhesive component having a melting temperature of from about 90–100° C.;
   (ii) from about 50 to 75% by weight of an α-olefinic, thermoplastic component having a melting temperature of from about 50–60° C.; and
   (iii) from about 20 to 80% by weight of one or more thermally-conductive fillers;

(b) forming said material into a self-supporting layer;

(c) applying said layer to one of said heat transfer surfaces;

(d) disposing said heat transfer surfaces in thermal adjacency to define said interface; and

(e) energizing said electronic component effective to heat said layer to a temperature which is above said phase transition temperature.

15. The method of claim **14** wherein said material has a phase transition temperature of from about 70–80° C.

16. The method of claim **14** wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

17. A thermally-conductive interface for interposition between a heat-generating electronic component having an operating temperature range above normal room temperature and a first heat transfer surface disposable in thermal adjacency with a second heat transfer surface of a thermal dissipation member, said interface comprising a self-supporting layer of a thermally-conductive material which is form-stable at normal room temperature in a first phase and substantially conformable in a second phase to said interface surfaces, said material having a transition temperature from said first phase to said second phase within the operating temperature range of said electronic component, and comprising a blend of:

(a) from about 25 to 50% by weight of an acrylic pressure sensitive adhesive component having a melting temperature of from about 90–100° C.;

(b) from about 50 to 75% by weight of an α-olefinic, thermoplastic component having a melting temperature of from about 50–60° C.; and

(c) from about 20 to 80% by weight of one or more thermally-conductive fillers.

18. The interface of claim **17** wherein said material has a phase transition temperature of from about 70–80° C.

19. The interface of claim **17** wherein said one or more thermally-conductive fillers is selected from the group consisting of boron nitride, alumina, aluminum oxide, aluminum nitride, magnesium oxide, zinc oxide, silicon carbide, beryllium oxide, and mixtures thereof.

* * * * *

ADHERENT FILM WITH LOW THERMAL IMPEDANCE AND HIGH ELECTRICAL IMPEDANCE USED IN AN ELECTRONIC ASSEMBLY WITH A HEAT SINK

Field of the Invention

The invention relates to an electronic circuit comprising a circuit pathway or trace made on a rigid or flexible printed circuit board substrate and an electronic assembly which uses the circuit in thermal communication with, but electrically insulated from a heat sink. The invention additionally relates to an electronic circuit assembly that uses a rigid or flexible substrate, an electrical insulation layer and a heat sink.

Background of the Invention

Electronic assemblies that include a circuit trace or pattern on a rigid or flexible printed circuit board, are known. Because heat is generated during the electrical operation of many such assemblies, a need exists for the effective removal and dissipation of heat. If the heat is not removed, circuit operation can be impaired or one or more parts of the assembly may be damaged or destroyed. A well known means for providing heat removal is the use of a heat sink, having substantial heat capacity and heat dissipation properties, as a part of the assembly. Heat flows from the active circuit into the heat sink and away from the source of heat. The heat sink operates through a large heat capacity and by heat dissipation through conduction, convection, radiation or a combination of these effects. The presence of a circuit pathway or circuit trace, on the flexible circuit, in contact with a conductive heat sink requires an electrically insulating layer between any active circuit path and any metallic portion of the heat sink. Ideally, the insulating layer comprises a material that has a maximized thermal conductivity (minimum thermal impedance) with optimized electrical insulation (high dielectric strength). Because close contact between the circuit and the heat sink improves heat dissipation, a

material that is both thermally conductive and electrically insulating is particularly desirable. Further, heat flow is optimized if the insulation is as thin as possible without losing electrical isolation.

The prior art describes a large variety of thermal dissipating schemes for cooling many types of heat generating devices. Gregory, U.S. Patent No. 4,858,073 describes a metal surface and a thermally laminated insulator film having a conductive foil layer. An active semiconductor device is attached to a heat conductor that is in contact with the foil layer to remove heat from the semiconductor. Heat flows from the semiconductor through the heat conductor into the foil to be dissipated. Butt, U.S. Patent numbers 4,849,857 and 5,014,159 describes a semiconductor package having a semiconductor chip bonded to an (e.g.,) copper core heat sink with refractory materials. The copper core can be further attached to a metallic heat sink. The semiconductor chip is wire bonded to the active printed circuit pattern. The package then is integrated into the active circuit using conventional components. Barker, III et al., U.S. Patent No. 5,175,613 describes a thermally conductive elastomer that is placed between the circuit and the heat sink. Mechanical devices are employed to compress the elastomer and maintain contact between the components of the package. No adhesive material is used to bond the chip to the heat sink. No detail is provided regarding the nature of the thermally conductive elastomer. DeGree et al., U.S. Patent No. 4,574,879 teaches a thermally conductive mounting pad for a solid state device such as a power transistor, SCR or triac. The mounting pad comprises at least a three-layer laminate. The laminate comprises, in a center layer, a filled polyimide (amide) containing a thermally conductive particulate such as aluminum oxide, boron nitride, etc. The two outside layers in the laminate comprise a silicone base rubber. DeGree et

al., U.S. Patent No. 4,810,563 teaches a thermally conductive laminate structure. The laminate can have up to five layers including two oppositely disposed outer metallic layers enclosing center composite layers. The center layers comprise films of polyimide (amide) filled with aluminum oxide, boron nitride or other suitable thermally conducting particulate. Squitieri, U.S. Patent No. 4,869,954 discloses a thermally conductive laminate having at least three layers; the center layer comprising a conventional glass, fiberglass, plastic film and metal foil layer. The two oppositely disposed external layers form from a curable liquid urethane material containing thermally conductive particulate. The liquid urethane material is formed into a coating on the center layer, is cured to form solid laminate structure. Anschel et al., U.S. Patent No. 4,914,551 teaches an electronic package adapted to cool a discrete electronic device such as a semiconductor (e.g., a silicon chip). The semiconductor device is positioned on a thin film substrate attached to a second substrate. A heat spreading surface is bonded to the semiconductor device surface and a heat sink is bonded to the heat spreading device. The heat spreading device is a bulk material such as silicon carbide, aluminum nitride, or copper clad material. An adhesive material is used to define a first interface between the semiconductor device and the heat spreader. The interface between the heat sink and the heat spreader is also insulated by a thermally conducted insulating adhesive. Hastings et al., U.S. Patent No. 5,285,108 describe the use of a thermally conductive material that is also electrically insulating. The material comprises silicone or urethane elastomer that is filled with known thermally conducting fillers.

Improved techniques are needed for removing heat from printed circuits. Circuits that generate substantial heat need an insulating layer that can

conduct substantial heat while maintaining substantial dielectric strength. As the electrical properties improve the thickness of the layer can often increase. Such thickness can result from higher amounts of fillers to increase thermal conductivity or from the use of thicker layers to achieve the required dielectric strength. These thick layers reduce the flexibility of the printed circuit, reduce thermal properties and additionally can increase the cost of the final product.

A need exists for a means of connecting a rigid or flexible printed circuit board to a heat sink that provides good electrical insulation, low thermal resistance and reduced assembly thickness.

Summary of the Invention

The invention resides in an electrical assembly having at least one flexible or rigid circuit substrate having at least one copper circuit trace on each side of the substrate. The circuit is bonded to a heat sink to form the assembly. The active metal circuit pattern, trace or traces are disposed on a side of the circuit substrate bonded to the heat sink and are insulated from the heat sink using an interposed or intermediate adherent film. The film comprises an unfilled thin polymer film or sheet that separates the metallic circuit traces from the heat sink. The heat sink and circuit are bonded to the insulating film using a filled adhesive layer disposed on opposite sides of the unfilled insulating film layer. The filled adhesive comprises a thermoplastic or thermosetting, adhesive or pressure sensitive adhesive (PSA) formulation containing a thermally conductive particulate filler material. The particulate material in the adhesive on the heat sink side may also be electrically conductive. However, any particulate in contact with an active circuit is preferably not electrically conductive. The film of the insulating layer is substantially free of any thermally

conductive filler. Preferred fillers are ceramic particulate. Using this combination of elements, a thermally conductive bond ply can be made having a thickness of less than 150 μm, preferably less than 135 μm can be used.

The rigid or flexible printed circuit board can be a circuit comprising a single hard board layer such as phenolic or epoxy, or a polymeric layer, having one or more circuit traces on opposite sides of the board or film or can be a multilayer film comprising two, three, four or more layers of circuitry bonded into a cooperating active circuit by interconnections between the layers. Metallic traces can also act to manage heat as thermal passageways or dissipation units. The heat sink can be a sheet of metallic material such as aluminum or copper. Alternatively, heat sinks having heat capacity and heat dissipation rates substantially greater than metallic sheets can also be used. Finned heat sinks or tabbed heat sinks or heat sinks having liquid coolant can be used.

One aspect of the instant invention provides an adherent film article having low thermal impedance and high dielectric strength that retains a high degree of flexibility. The adherent film can have multiple layers. For example, the adherent film assembly can comprise a first filled thermally conducting adhesive layer, an unfilled polymeric film having high dielectric strength, and a second filled thermally conducting adhesive layer. The first adhesive layer requires dielectric strength sufficient to prevent trace to trace shorting. The two adhesive layers of the film increase the thermal conductivity of the assembly by maintaining close contact between the active circuit and the heat sink. The layers provide useful electrical dielectric strength. The first and/or the second adhesive layer contain a thermally conductive material such as a ceramic particulate to increase the thermal conductivity

of the layer. For the thin film layer an unfilled polymeric film is chosen having good dielectric strength. This film layer is as thin as possible to minimize thermal resistance while providing electrical insulation. Suitable materials for this layer include, for example, polyesters, polyetherimides, polyimides and other equivalent engineering resins. The adherent film assembly of the invention has a combination of physical, thermal, and electrical properties that are well suited for assembly processes (e.g., soldering) mounting printed circuits on to a heat sink or other heat dissipating devices.

Another aspect of the instant invention is an electronic assembly that comprises a printed circuit board attached to a heat sink by the adherent film article. In this electronic assembly the adherent film provides superior heat dissipation into the heat sink. Performance is not impaired by thermal stress, and the unfilled polymeric layer provides electrical insulation between the printed circuit and the heat sink.

A further aspect of the invention is a method of assembling the electronic package comprising bonding of an assembly made from a thin dielectric film and filled adhesive to the backside of a circuit, followed by bonding to a heat sink at least partly coated with a layer of thermally conductive adhesive.

Brief Description of the Figure

The Figure is a perspective of an exploded view of a double sided printed circuit board having exposed portions. The flexible printed circuit board can be adhered to the heat sink using an intermediate insulating layer.

Detailed Description of the Invention

The electronic assemblies of the invention use a thin insulating polymer film disposed between an active

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circuit and a heat sink using a filled, thermally conductive adhesive. The film should be selected to minimize thermal impedance while maintaining adequate dielectric strength. Thermal impedance is reduced by reducing the thickness of the film. However, as the film thickness is reduced, the insulating value or dielectric strength is reduced. Below a certain thickness, the film cannot be relied upon for providing adequate electrical insulation. Preferred films have a maximum thickness of less than 15 μm, about 1 to 15 μm, preferably about 5 to 12 μm. Typically the dielectric strength of the layer must be at least 300 volts (ac) preferably at least 1000 volts (ac). The thermal properties of the film can be characterized with a thermal impedance (less than about 100°C-mm^2/watt, preferably less than about 50°C-mm^2/watt). Any film that corresponds to these dimensions and thermal and dielectric strength properties can be used as an insulating layer. Lastly the films are substantially unfilled. Commonly in this art, insulating films have been used containing a substantial portion of a thermally particulate filler material to improve the thermal conductivity. Such thermally conductive particulate typically comprise a ceramic material. The films of this invention are substantially free of any such filler material. The absence of filler permits the use of a film of thin film at low cost. A broad class of potential film materials are known. Preferred film materials include thermoplastic polyesters, polyimides, polyetherimides and equivalent engineering resins.

Preferred films are made from aromatic dicarboxylic acids and alkane diols. Preferred alkane diols and the polyesters include ethylene glycol, 1,4-butanediol, 1,6-hexanediol, 1,4-cyclohexanediol and other aliphatic diols having from 2-12 carbon atoms in a saturated linear or cyclic alkyl structure. Preferred aromatic acids in the manufacture of the polyesters of the

invention include terephthalic acid (1,4 benzene dicarboxylic acid) terephthalic dicarboxylic acids, (e.g.,), 2,6-naphthalene dicarboxylic acid, 2,7-naphthalene dicarboxylic acid, etc. The preferred polyester film composition of the invention is a poly (ethylene-co-2,6-naphthalene dicarboxylic) (PEN).

Polyimides are condensation polymers derived from bifunctional carboxylic anhydrides and primary amines. The imide structure -CO-NR-CO-, having a linear or heterocyclic unit along the polymer backbone, is characteristic. Aromatic heterocyclic polymers exhibit outstanding mechanical properties and excellent stability. Polyimides can be prepared from an aliphatic diamine and an aromatic tetracarboxylic acid in a multistep sequence in the melt reaction. An alternative preferred preparation from aromatic tetracarboxylic dianhydrides is more versatile. Aromatic diamines such as 1,4-phenylene diamine, 1,3-phenylene diamine, 4,4'-methylene diphenylene diamine, hexamethylene diamine, 4,4'-oxydianiline (ODA), etc. can be reacted with the dianhydride.

Polyetherimides are an engineering plastic well known in the art. The techniques used to produce polyetherimides are also well known. See, for example, United States Patent No. 4,297,474. Typically in the practice of the manufacture of polyetherimides, a substituted aromatic bis-amide is reactive with an alkali metal phenate to form the polyether amide. The alkali metal phenate can be either monocyclic or polycyclic and can contain two phenate groups. The phenates are reacted with materials as described above containing the
-O-phenylene-O- group. Alternatively the polyetherimide can be made by a conventional condensation of diamines and an ether containing dianhydride. Preferred polyetherimide resins are ULTEM® polyetherimide (PEI) resins manufactured by G.E. Plastics Company.

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Insulating films discussed above commonly are coated with a thermally conductive adhesive layer before use. The adhesive layer is made thermally conductive using a minimum film thickness and a substantial proportion of the heat conductive filler material. Preferred fillers are metallic, inorganic or ceramic particulate that can be dispersed or suspended in the adhesive material prior to coating the polymer film. The particle size of the particulate typically ranges from about 0.1 to 30 microns, preferably 1.0 to 25 microns. Useful thermally conducting but electrically insulating ceramic materials include aluminum oxide, beryllium oxide, magnesium oxide, titanium oxides, zinc oxide, boron nitride, aluminum nitride, silicon nitride, silicon carbide, silica, diamond, etc. and mixtures thereof. The thermally conducting material within the adhesive layer, in contact with the heat sink can be the particulate above or the following Cu, Al, Ag, Au, Ni, Zn, Fe, Pd, Pb, Sn, solder, graphite, carbon, or mixtures thereof.

A variety of adhesive types can be used. Both thermoplastic or thermosetting adhesives are available. The preferred adhesive comprises a solvent borne or based, hot melt thermoplastic adhesive solvent borne, water borne, or hot melt thermoplastic adhesive. Solvent borne adhesive systems permit better dispersal of particulate filler and also improved consolidation of the filler matrix upon drying. Such systems are typically composed of soluble or dispersed acrylic epoxy, polyimide, polyester or polyurethane resins. Water borne adhesives can be used if compatible with filler. Thermoplastic hot melt adhesives typically comprise a thermoplastic polymer such as an ABA block copolymer (wherein A is polystyrene and B is a polybutadiene or polyisoprene), polyethylene, poly(ethylene-co-vinyl acetate), an acrylic resin, a polystyrene resin, or other known polymer, in

combination with a tackifier, a plasticizer or extender. These materials are typically made by combining the materials in a melt condition, blending until uniformed and packaging the adhesives for transfer to point of use. Thermosetting adhesives operate by chemically cross-linking the composition between polymer backbone chains resulting in a highly cross-linked reaction product. The most common thermosetting adhesive types include epoxy adhesives and urethane adhesives. Typically the adhesives contain about 10 to 50 vol-%, preferably about 30 to 40 vol-% of the thermally conductive inorganic filler particulate. In manufacturing the insulating films of the invention, the film is typically coated on both sides of the film, with a layer of filled adhesive composition.

Typically, the thickness of the adhesive film is about 15 to 60 microns, preferably 25 to 40 microns. The thickness of the adhesive film is minimized to obtain adequate bonding while maximizing thermal conductivity. The thermal conductivity of the filled adhesive composition should range between about 0.5 - 20 watts/m-K, preferably greater than 1 watts/m-K.

A major limiting factor for any electronic circuit consuming electric power is the high thermal resistance between the component and the ambient surroundings. To increase the heat handling capacity of any circuit, the circuit must be mounted in intimate thermal contact with a heat sink. A heat sink is simply a mechanical device with an improved heat transfer capability, i.e., heat transfer from the device into the ambient atmosphere. Heat sinks often consist of a metal chassis, a metal sheet, a finned structure with or without forced air cooling or even a liquid cooled metal structure for maximum heat transfer and minimum volume. The available shapes and sizes vary widely. The choice of a heat sink for a particular application depends on the net thermal resistance from the circuit to the ambient atmosphere in

terms of required power dissipation. Preferred heat sinks in this application are thin metallic sheets, preferably aluminum having a thickness of about 0.020-0.0125 inches. For circuits having higher power dissipation, thicker aluminum can be used, alternatively finned sheets or liquid cooled structures can be used.

Rigid printed circuit substrate material can include rigid boards made from phenolic, epoxy, epoxy fiberglass, and other conventional rigid circuit board substrates.

The flexible printed circuit boards of the invention are typically made from a flexible metal-film laminate material. The laminate can comprise a polymer film layer having a metal layer on each surface of a film. Both adhesiveless and adhesive containing laminates can be used. Films that can be used for forming the metal film laminates used in the circuit boards of the invention are commonly organic film-forming compositions that can be formed from a variety of common polymeric films including addition polymers, condensation polymers, natural polymers, treated films, thermosetting or thermoplastic resins.

Useful thermosetting resins include phenolic resins, epoxy resins, polyurethane resins, thermosetting polyester resins, silicone resins, etc. Engineering plastics such as polyamide (Nylon), aromatic polyester, polyetherimide, polyether ether ketone, polysulfone, and polyphenylene ether; crosslinkable resins obtained by compounding an organic peroxide as a crosslinking agent and a radical polymerizable polyfunctional compound, a thermosetting resin and the like can be used. Because of the nature of thermosetting resins, they cannot be further heat processed without severe distortion or destruction.

Polyimide film can be used in the preferred film circuit laminate. Preferred polyimides are typically made by a two step reaction involving contacting a

tetrabasic acid dianhydride with an aromatic diamine giving first a polyamic acid that is then converted by heat or catalyst into a high molecular weight, linear polyimide. Such polyimides are easily produced as film or sheet.

Thermoplastic resins are also useful in the laminate films of the invention. Useful addition polymers include poly alpha-olefins, polyethylene, polypropylene, poly 4-methyl-pentene-1, ethylene/vinyl copolymers, ethylene vinyl acetate copolymers, ethylene acrylic acid copolymers, ethylene methacrylate copolymers, ethyl-methylacrylate copolymers, etc.; thermoplastic propylene polymers such as polypropylene, ethylene-propylene copolymers, etc.; vinyl chloride polymers and copolymers; vinylidene chloride polymers and copolymers; polyvinyl alcohols, acrylic polymers made from acrylic acid, methacrylic acid, methylacrylate, methacrylate, acrylamide and others. Fluorocarbon resins such as polytetrafluoroethylene, polyvinylidiene fluoride, and fluorinated ethylene-propylene resins. Styrene resins such as a polystyrene, alpha-methylstyrene, high impact polystyrene acrylonitrile-butadiene-styrene polymers and others.

A variety of condensation polymers can also be used in the manufacture of the laminates of the invention including nylon (polyamide) resins such as nylon 6, nylon 66, nylon 10, nylon 11, nylon 12, etc. A variety of polyester materials can be made from dibasic aliphatic and aromatic carboxylic acids and di- or triols. Representative examples include poly(ethylene-co-terephthlate), poly(butylene-co-terephthlate), poly(ethylene-co-naphthalate) and others.

Polycarbonates can also be used in the manufacture of the circuit invention. Such polycarbonates are long chained linear polyesters of carbonic acid and dihydric phenols typically made by reacting phosgene ($COCl_2$) with bisphenol A materials resulting in transparent, tough,

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dimensionally stable plastics. A variety of other condensation polymers are used including polyetherimide, polysulfone, polyethersulfone, polybenzazoles, aromatic polysulfones, polyphenylene oxides, polyether ether ketone and others.

Preferred material for use in the laminate of the invention are polyester film materials such as poly-ethylene-terephthlate, polybutylene terephthlate and polyimide materials. These film materials are sold by duPont, Allied-Apical, Teijin, Kanega-fuchi, as Mylar®, Kapton®, Apical®, Upilex®, etc., films.

Metals

The metal useful in forming the metal film laminate of the circuit boards of the invention are often shiny, metallic layers not subject to substantial corrosion from atmospheric conditions and have substantial electrical conductivity. Preferred metals for use in forming the laminate structures of the invention include aluminum, copper, gold, silver, etc.

To make an adhesive metal laminate, a foil can be adhered to a hard board or film substrate with a conventional laminating adhesive.

To make the adhesiveless metal layer, the film can be contacted with a source of a conductive layer. Preferably, a source of metal vapor is used to form a metallized layer on the plasma treated film. Vapor metallization is a low pressure, high temperature (energy) process in which metal vapor is formed. A variety of other layers can be used including carbon, conductive polymers, etc.

The metallization step can be each carried out at relatively low pressure, typically less than 200 Torr. This process can be carried out in a single chamber which is divided into sections operated at a pressure that is optimized for multiple metal addition. Typically, the metallization occurs at pressures less than 0.5 Torr.

The metallized film is particularly suited for the subsequent formation of thick metal layers such as those useful in the end uses discussed above. Such layers can be formed in a variety of techniques, however, electroplating and electroless plating are the most commonly used metal layer formation techniques.

Electroplating is the electrodeposition of an adherent metallic coating on an electrode surface to form a metal deposit. The electrode surface being treated is made the cathode in an electroplating solution or bath. Such baths are typically aqueous solutions from which metal is reduced by the flow of an electric current through a solution of the metal salt. In performing electroplating of metal on a conductive electrode, the electrode or substrate is often cleaned, rinsed, dipped in acid or is subject to other pretreatment or substrate preparation. In operating electroplating techniques, the substrate is immersed into a solution and necessary DC power is applied typically from metallic anodes to the substrate cathode. The solutions are often agitated and the temperature current metal concentration and other variables are closely controlled using well known principles.

In the preparation of metal laminates of the invention, the laminate metal is typically copper plated onto a substrate having a metal layer prepared using the copper metallization techniques. Useful copper layers, can also be formed using electroless plating which is the controlled autocatalytic deposition of a continuous film by the interaction, in a solution of metal salt between a metal and a chemical reducing agent. Electroless deposition can give films of metals, alloys, metallic compounds, and composites on both conductive and non-conductive surfaces. Electroless solutions contain a metal salt, reducing agent, a pH adjuster or buffer, a complexing agent and one or more additives to control solution stability, film properties, deposition

rates, etc. Primarily, nickel, copper, gold and silver are plated using electroless techniques. The advantage of electroless plating is the ability to plate metal on non-conductive or poorly conductive surfaces.

Once the adhesive or adhesiveless metal layer(s) is formed, a printed wiring board can be made by forming the circuit pattern in metal on the film. The pattern can be formed by an etching process or by a semi-additive pattern plating process. In an etching process, a resist and basic etchant baths are used to selectively remove copper leaving the pattern. Alternatively, a conductive circuit pattern can be formed on the laminate of the invention using a semi-additive technique. In such a technique, the circuit pattern is formed in a way to significantly reduce the amount of metal removed through an etching step. In the semi-additive technique, after the first metal layer is formed using metallization, a resist is formed on the first layer. The resist leaves revealed, the first metal layer in the pattern of the desired circuit. Onto the revealed pattern is plated a thick, 0.1 to 40 μm layer of copper using commonly electroplating or electroless techniques. After the second metal layer in the desired pattern is complete, the resist can be removed leaving the thick metal pattern and in the areas revealed by the removal of resist, the thin metallized layer. The remaining revealed metallized areas are then removed using a light etch. The metallized layers are thin and require brief etching substantially reducing the amount of metal removed, the amount of etchant consumed and substantially reduces the amounts of waste materials. The technology in Swisher, U.S. Patent No. 5,112,462 can be used to make the flexible, polymer-metal circuit.

The appropriately patterned double sided printed circuit board is manufactured into a finished circuit by attaching active and passive components to one surface

of the board. The opposite surface of the circuit board is attached to the heat sink through the disclosed insulating layer. The active circuits can be attached to the printed circuit board by any fabrication technology. However, a preferred method of attaching the active components involves surface mounting of the active components. The use of surface mount technology in attaching active components to one surface of the double sided printed circuit board of the invention results in a side free of any active component or attachment structures that would interfere in thermal transfer to the heat sink. The noncomponent side of the circuit board comprises a flat surface having only circuit patterns, ground plane, logos or other etched patterns overlying the flexible film material. As such, the flat surface is ideal for attachment through the adhesive coated layer to the heat sink. The flat surface is thermally connected to the heat sink over the entire surface. No gaps arise due to active component or attachment structure interference. Such a structure maximizes thermal conductivity.

Different processing techniques may be used to bond the surface mount components to the footprints of bonding pads formed in the circuit board. For example, for bonding flip chips (i.e., unpackaged integrated circuit chips having solder bumps formed on one side thereof), one preferred direct chip attachment mechanism in U.S. Patent No. 5,261,593, issued to Casson et al. According to the Casson et al. process, a low temperature solder paste is registered on contact pads on the overlay . One or more flip chips are registered on the overlay with the solder bumps on the chips centered on the solder paste on the contact pads. The solder paste is then reflowed by heating the entire assembly as a whole in an infrared reflow oven or other heat applying mechanism. The solder bumps and solder paste then form homogenous compositions which solidify

to provide a mechanical and electrical interconnection between the flip chips and the circuit board. Many other direct chip attachment techniques, such as tape automated bonding (tab), wire lead bonding C4, etc. may be used in the alternative, and that different materials, such as solders, solder pastes, conductive adhesives, etc. may be used to bond solder bumps or leads of the surface mount components to the circuit board.

Surface mount technology or assembly of flexible circuits are well matched. Components using surface assembly can take a wide variety of package sizes and package types. Typical components include resistors, capacitors, inductors, integrated circuits, diodes, transistors, resistor arrays and others. A variety of integrated circuit packaging can be used including chip carriers, dual in line packages, solder bump technology, direct wire interconnections and others can be used. Conventional soldering techniques can be used including IR reflow, heat probe, wave soldering and other techniques.

The resulting circuits, with attached heat sinks, of the invention can be used in a variety of applications where thermal control is important including radio frequency circuits, power circuits, high frequency circuits, circuits exposed to increased temperatures, etc. One preferred application for the technology of this invention is in automotive applications. Such automotive applications can include engine controllers, automatic breaking system controllers, pollution control modules, automotive radios, etc. or any other useful automotive application that can be mounted in the engine compartment, near exhaust systems, or in the vicinity of heated braking elements.

Detailed Description of the Figure

The heat sink 10 comes into contact with the adhesive layer 21 as the unfilled polymeric film layer 20, having an adhesive layer 21 on the opposite side of the polymeric layer 20. The flexible printed circuit board layer 30 having circuit traces 31 on one side of the flexible layer and circuit element 32 on the opposite side of the layer is adhered to the adhesive 21 on the insulating layer 20. Insulating layer 20 prevents conduction of electricity from circuit portion 32 to heat sink 11. The insulating layer covers all active portions of the circuit pattern 32. The surface of the printed circuit board 30 that does not contact the insulating layer can be coated with a solder resist or other resist coating. The printed circuit board can be of any design and can have virtually any circuit pattern including surface contact pads, edge connectors or mounting locations for passive devices, resistors, capacitors, inductors or active components such as diodes, transistors, integrated circuits or power devices such as power transistors, SCR's, triacs, and other rectifiers, inverters, transformers, inductors, capacitors, resistors and others. The printed circuit board can extend past the edge of the aluminum heat sink if desired. However, any portions of the printed circuit board having substantial heat generation should come in contact with the heat sink. In the Figure, the ground plane 33 of the reverse side of the printed circuit board 30 extends past the edge of the aluminum heat sink at 33.

The following examples and data illustrate specific embodiments of the invention. The examples and data contain information regarding the structures and manufacturing techniques of the adhesive coated insulating film of the invention and to the assemblies comprising a printed circuit board, a heat sink and the intermediate adhesive film. Further, the thermal and

electrical properties of the assembly and test methods for measurement are recited. The following contains a best mode:

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TABLE I

Sample	Description	Thermal Impedance °C-mm^2/watt*	Dielectric Strength KV ac. ASTM-D-149
1	6μm PEN 2 x 45 μm Bergquist PSA**	150	3.1
2	12μm PEN 2 x 45 μm Bergquist PSA	190	6.1
3	6μm PEN 2 x 35 μm Sheldahl 713-51***	100	5.8
4	12μm PEN 2 x 35 μm Sheldahl 713-51	140	7.3
5	5μm PEI 2 x 35 μm Sheldahl 713-51	80	2.4
6	8μm PEI 2 x 35 μm Sheldahl 713-51	95	5.7
7	14μm PEI 2 x 35 μm Sheldahl 713-51	125	6.4

* Theoretical impedance.

** Has a k of 0.9 watts/m-K.

*** Has a k of 1.0 to 2.0 watts/m-K.

In these constructions the Bergquist PSA is a filled acrylic with a thermal conductivity of 0.9 watts/m-K while the Sheldahl adhesive 713-51 is a filled thermoplastic/thermoset with a thermal conductivity of between 1.0 and 2.0 watts/m-K.

The foregoing specification examples, data, drawings and discussion illustrate embodiments of the invention that has been developed. A variety of embodiments of the invention can be made without departing from the spirit or scope of the invention. The invention resides in the claims hereinafter appended.

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WE CLAIM:

1. An assembly comprising an electronic circuit electrically insulated from, but in thermal communication with a heat sink, the assembly comprising:

(a) a heat sink;

(b) an electronic circuit, comprising at least one substrate layer and a metallic circuit trace, that produces heat as a result of operation; and

(c) disposed between the circuit and the heat sink, an insulating layer having a minimum thermal impedance of 250°C-mm^2/watt and a minimum dielectric strength of 400 volts (ac), the layer comprising:

(i) a first thermally conducting adhesive layer having a thickness less than 60μ, in contact with the heat sink, comprising an adhesive and about 10 to 50% by volume of a thermally conductive solid particulate;

(ii) an unfilled polymeric film layer having maximum a thickness less than 15μ; and

(iii) a second thermally conducting adhesive layer having a thickness less than 60μ, in contact with the circuit, comprising an adhesive and about 10 to 50% by volume of a thermally conductive electrically insulating solid particulate;

wherein the substrate and insulating layer has a maximum thickness of about 5 mm.

2. The assembly of claim 1 wherein the circuit comprises two or more layers of substrate each supporting at least one circuit trace.

3. The assembly of claim 1 wherein the unfilled polymeric film layer comprises a polyester or a polyimide.

4. The assembly of claim 3 wherein the unfilled polyester polymeric film layer comprises a polyethylene naphthalate.

5. The assembly of claim 3 wherein the polyester is a polyethylene terephthalate.

6. The assembly of claim 1 wherein the unfilled polymeric layer comprises a polyether ether ketone, a polyphenylene sulfide.

7. The assembly of claim 3 wherein the unfilled polyimide polymeric film layer comprises a polyetherimide or a polyimide.

8. The assembly of claim 1 wherein the thermally conducting adhesive layer comprises an epoxy adhesive.

9. The assembly of claim 1 wherein the thermally conducting adhesive layer comprises an acrylic adhesive.

10. The assembly of claim 1 wherein the thermally conducting material within an adhesive layer comprises a thermally conductive ceramic material.

11. The assembly of claim 10 wherein the thermally conducting ceramic material within an adhesive layer is independently selected from the group consisting of aluminum oxide, beryllium oxide, magnesium oxide, titanium oxide, zinc oxide, boron nitride, aluminum nitride, silicon nitride, silicon carbide, silica, diamond, zirconium oxide, zinc oxide, tin oxide, copper oxide, antimony oxide, and mixtures thereof.

12. The assembly of claim 1 wherein the thermally conducting material within the adhesive layer adjacent to the heat sink is Cu, Al, Ag, Au, Ni, Zn, Fe, Pd, Pb, Sn, solder, graphite, carbon or mixtures thereof.

13. The assembly of claim 1 wherein the impedance of the thin film layer is about 300 v (ac).

14. The assembly of claim 1 wherein the thermal conductivity of the first adhesive layer is greater than about 0.5 watt/m-K.

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15. The assembly of claim 1 wherein the thermal conductivity of the second adhesive layer is greater than about 0.5 watt/m-K.

16. The assembly of claim 1 wherein the thermal impedance of the insulating layer is less than about 100°C-mm^2/watt.

17. The assembly of claim 1 wherein the circuit comprises surface mounted active or passive components.

18. The assembly of claim 1 wherein the flexible circuit has at least one circuit trace on each side and plated through holes.

19. The assembly of claim 1 wherein the circuit additionally comprises a metallic circuit trace providing a thermal passageway.

20. The assembly of claim 19 wherein the thermal passageway comprises a metallized via providing a thermal passageway through a substrate.

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AMENDED CLAIMS

[received by the International Bureau on 13 September 1996 (13.09.96); original claim 1 amended; new claims 21-35 added; remaining claims unchanged (4 pages)]

1. An assembly comprising an electronic circuit electrically insulated from, but in thermal communication with a heat sink, the assembly comprising:

(a) a heat sink;

(b) an electronic circuit, comprising at least one substrate layer and a metallic circuit trace, that produces heat as a result of operation; and

(c) disposed between the circuit and the heat sink, an insulating layer having a maximum thermal impedance of 250°C-mm^2/watt and a minimum dielectric strength of 400 volts (ac), the layer comprising:

(i) a first thermally conducting adhesive layer having a thickness less than 60μ, in contact with the heat sink, comprising an adhesive and about 10 to 50% by volume of a thermally conductive solid particulate;

(ii) an unfilled polymeric film layer having maximum a thickness less than 15μ; and

(iii) a second thermally conducting adhesive layer having a thickness less than 60μ, in contact with the circuit, comprising an adhesive and about 10 to 50% by volume of a thermally conductive electrically insulating solid particulate;

wherein the substrate and insulating layer has a maximum thickness of about 5 mm.

2. The assembly of claim 1 wherein the circuit comprises two or more layers of substrate each supporting at least one circuit trace.

3. The assembly of claim 1 wherein the unfilled polymeric film layer comprises a polyester or a polyimide.

15. The assembly of claim 1 wherein the thermal conductivity of the second adhesive layer is greater than about 0.5 watt/m-K.

16. The assembly of claim 1 wherein the thermal impedance of the insulating layer is less than about 100°C-mm²/watt.

17. The assembly of claim 1 wherein the circuit comprises surface mounted active or passive components.

18. The assembly of claim 1 wherein the flexible circuit has at least one circuit trace on each side and plated through holes.

19. The assembly of claim 1 wherein the circuit additionally comprises a metallic circuit trace providing a thermal passageway.

20. The assembly of claim 19 wherein the thermal passageway comprises a metallized via providing a thermal passageway through a substrate.

21. An insulating laminate having a maximum thermal impedance of 250°C-mm²/watt and a minimum dielectric strength of 400 volts (ac), the layer comprising:

(i) a first thermally conducting adhesive layer, having a thickness less than 60μ, comprising an adhesive and about 10 to 50% by volume of a thermally conductive solid particulate;

(ii) an unfilled polymeric film layer having maximum a thickness less than 15μ; and

(iii) a second thermally conducting adhesive layer, having a thickness less than 60μ, comprising an adhesive and about 10 to 50% by volume of a thermally conductive electrically insulating solid particulate;

wherein the laminate has a maximum thickness of about .135 mm.

22. The laminate of claim 21 wherein the unfilled polymeric film layer comprises a polyester or a polyimide.

23. The laminate of claim 22 wherein the polyester polymeric film layer comprises a polyethylene naphthalate.

24. The laminate of claim 22 wherein the polyester is a polyethylene terephthalate.

25. The laminate of claim 21 wherein the unfilled polymeric layer comprises a polyether ether ketone, a polyphenylene sulfide.

26. The laminate of claim 22 wherein the polyimide layer comprises a polyetherimide or a polyimide.

27. The laminate of claim 21 wherein the thermally conducting adhesive layer comprises an epoxy adhesive.

28. The laminate of claim 21 wherein the thermally conducting adhesive layer comprises an acrylic adhesive.

29. The laminate of claim 21 wherein the thermally conducting material within an adhesive layer comprises a thermally conductive ceramic material.

30. The laminate of claim 29 wherein the thermally conducting ceramic material within an adhesive layer is independently selected from the group consisting of aluminum oxide, beryllium oxide, magnesium oxide, titanium oxide, zinc oxide, boron nitride, aluminum nitride, silicon nitride, silicon carbide, silica, diamond, zirconium oxide, zinc oxide, tin oxide, copper oxide, antimony oxide, and mixtures thereof.

31. The laminate of claim 21 wherein the thermally conducting material within an adhesive layer to be put adjacent to a heat sink is Cu, Al, Ag, Au, Ni, Zn, Fe, Pd, Pb, Sn, solder, graphite, carbon or mixtures thereof.

32. The laminate of claim 21 wherein the impedance of the thin film layer is about 300 v (ac).

33. The laminate of claim 21 wherein the thermal conductivity of the first adhesive layer is greater than about 0.5 watt/m-K.

34. The laminate of claim 21 wherein the thermal conductivity of the second adhesive layer is greater than about 0.5 watt/m-K.

35. The laminate of claim 21 wherein the thermal impedance of the laminate is less than about 100°C-mm^2/watt.

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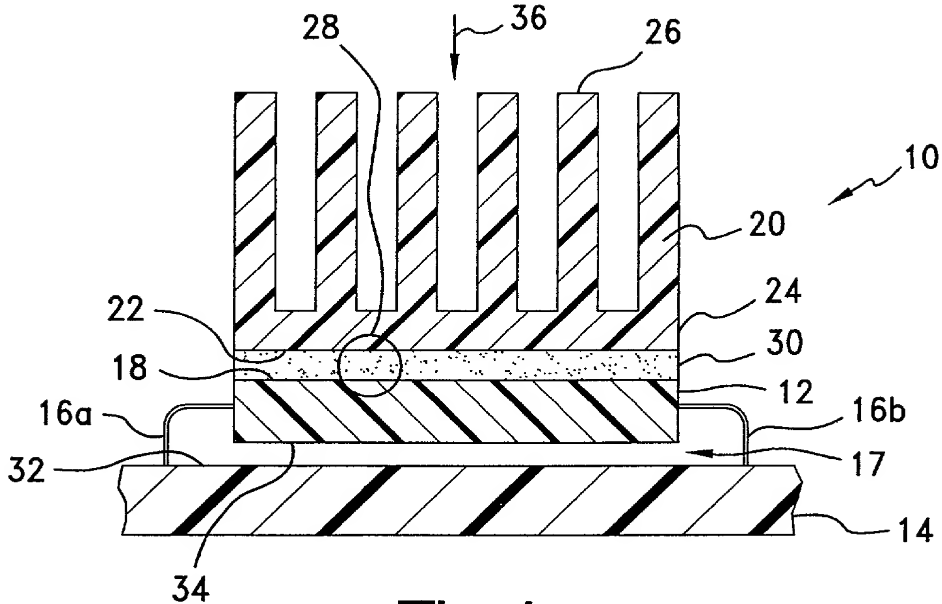

Fig. 1

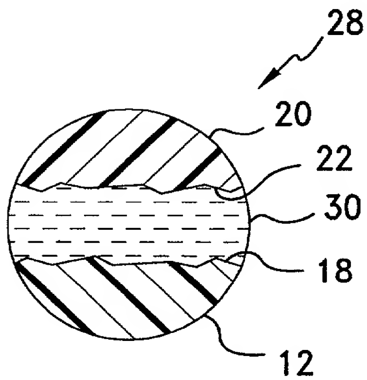

Fig. 2

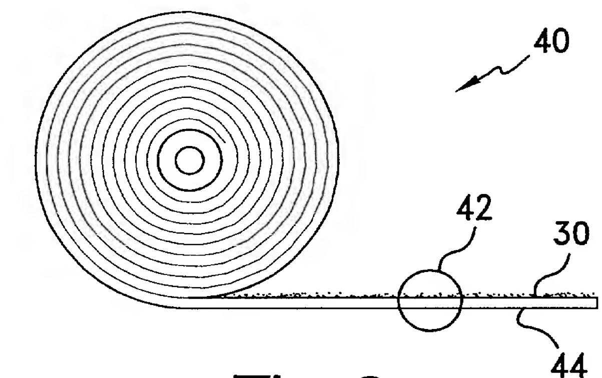

Fig. 3

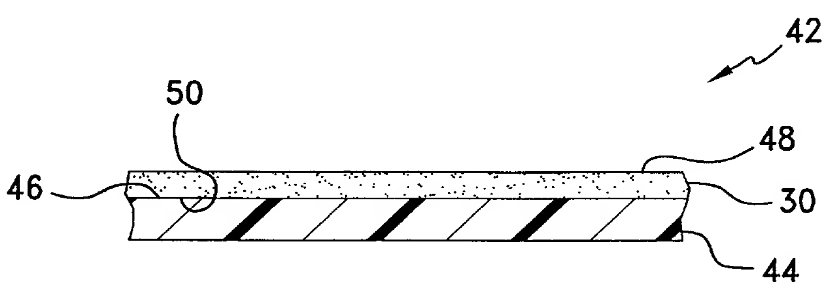

Fig. 4

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REISSUE APPLICATION DECLARATION BY THE INVENTOR	Docket Number (Optional)

As a below named inventor, I hereby declare that:
My residence, mailing address and citizenship are stated below next to my name.
I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is described and claimed in patent number 6,054,198, granted April 25, 2000, and for which a reissue patent is sought on the invention entitled Conformal Thermal Interface Material For Electronic Components, the specification of which

[XX] is attached hereto.

[ ] was filed on ____________ as reissue application number ____/__________ and was amended on ______________.
(If applicable)

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.
I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.
I verily believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)

[ ] by reason of a defective specification or drawing.

[XX] by reason of the patentee claiming more or less than he had the right to claim in the patent.

[ ] by reason of other errors.

At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, such must be stated with an explanation as to the nature of the broadening:

1. As issued, independent claims 1 and 9 of U.S. Patent No. 6,054,198 ("the '198 patent") recite a phase change material (PCB) which is formulated as a blend of at least one resin or wax component and at least one thermally-conductive filler.
2. It is possible, however, that those claims might be construed, depending upon the prevailing rules of claim construction then in effect, as excluding formulations based on mixtures of one or more resins and one or more waxes.
3. In fact, the specification as filed of the '198 patent describes at col. 8, ll. 16-65 a representative embodiment which is based on a mixture of a resin, namely a PSA component, and a wax, namely an α-olefinic thermoplastic component such as Vybar® 260;
4. Although not termed a "wax" in the specification, α-olefinic thermoplastics such as Vybar® 260 are generally considered to be waxes and are referred to as such in the following issued U.S. Patent Nos. (copies of which are annexed hereto): 4,217,320 [*See* col. 2, ll. 59-68]; 4,515,740 [*See* col. 7, ll. 58-63]; 5,994,020 [*See* col. 13, ll. 47-63]; and 6,080,800 [*See* col. 7, ll. 29].
5. The accompanying preliminary amendment therefore amends claims 1 and 9 to expressly include PCB formulations which are mixtures of resins and waxes.

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(REISSUE APPLICATION DECLARATION BY THE INVENTOR, page 2)

Docket Number (Optional)

All errors corrected in this reissue application arose without any deceptive intention on the part of the applicant. As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the United States Patent and Trademark Office connected therewith.

Name(s)	Registration Number
John A. Molnar, Jr.	36,611

Correspondence Address: Direct all communications about the application to:

[XX] Customer Number 23984 → Place Customer Number Bar Code Label here

Type Customer Number here

[XX] Firm or Individual Name	JOHN A. MOLNAR, JR.				
Address	Parker-Hannifin Corporation				
Address	6035 Parkland Boulevard				
City	Cleveland	State	Ohio	Zip	44124
Country	USA				
Telephone	(216) 896-2212	Fax	(216) 896-4027		

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.

Full name of sole or first inventor (given name, family name) MICHAEL H. BUNYAN	
Inventor's signature Michael Bunyan	Date 11/15/00
Residence 21 Essex Place Chelmsford, Massachusetts 01824	Citizenship US
Mailing Address 21 Essex Place, Chelmsford, Massachuseets 01824	
Full name of second joint inventor (given name, family name) MIKSA de SORGO	
Inventor's signature Miksa de Sorgo	Date 11/15/2000
Residence 3 Shamrock Road Windham, New Hampshire 33087	Citizenship US
Mailing Address 3 Shamrock Road, Windham, New Hampshire 33087	
Full name of third joint inventor (given name, family name)	
Inventor's signature	Date
Residence	Citizenship
Mailing Address	

☐ Additional joint inventors are named on separately numbered sheets attached hereto.